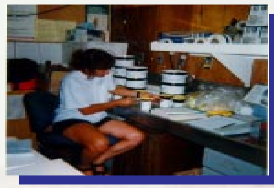
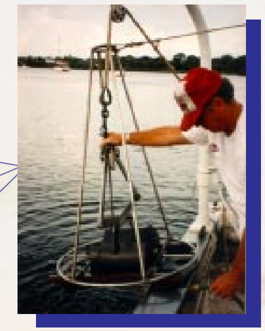
Sediment Toxicity in U.S. Coastal Waters





Coastal Monitoring and Bioeffects Division
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Sediment Toxicity In U.S. Coastal Waters

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INTRODUCTION

Through municipal sewage, agricultural runoff, industrial effluents, and various other routes, potentially toxic contaminants find their way into our nation's estuarine and coastal waters. These contaminants accumulate in different components of coastal ecosystems and are distributed in different forms. Most of them can become attached to suspended particles in the water. As these particles sink to the bottom they carry the toxicants with them, ultimately leading to their accumulation in fine-grained sedimentary deposits. Often, the concentrations of toxicants are much higher in sediments than in the overlying water. Under certain conditions, such as high winds, strong currents, or changes in ambient chemistry, accumulated contaminants are released, resuspended, or dispersed in the water. Sediments thereby can serve both as a sink and a source of contaminants and, therefore, can pose serious threats to the health of resident marine life. Many contaminants are accumulated in plant and animal tissues in concentrations much higher than in their environment, i.e. air, water, sediment. The National Research Council (1989), the U.S. Environmental Protection Agency (1994), and the House Committee on Merchant Marine and Fisheries (1989) have all expressed the concern that chemical contamination of sediments poses serious threats to the health of the Nation's coastal waters and that the problem of sediment contamination is widespread.

Toxic chemicals can also be transferred from sediments into food webs and affect animals quite distant from a contaminated site. Toxicants may be ingested by those animals living on or in sediments (i.e., the worms and clams that burrow through the sediments feeding on organic matter as well as the snails and amphipods grazing on algae). In turn, contaminated herbivores and omnivores may be eaten by carnivorous fish and waterfowl. Ultimately, larger contaminated coastal fauna may become the prey of still larger wildlife. Contaminants that do not metabolize quickly and those that are deposited in fatty tissues accumulate in food chains in increasingly larger amounts. They can cause cancerous lesions and organ disorders or interfere with an animal's repro-

Figure 1. *Location of 22 coastal embayments sampled by NOAA for sediment toxicity during 1991 - 1996.*

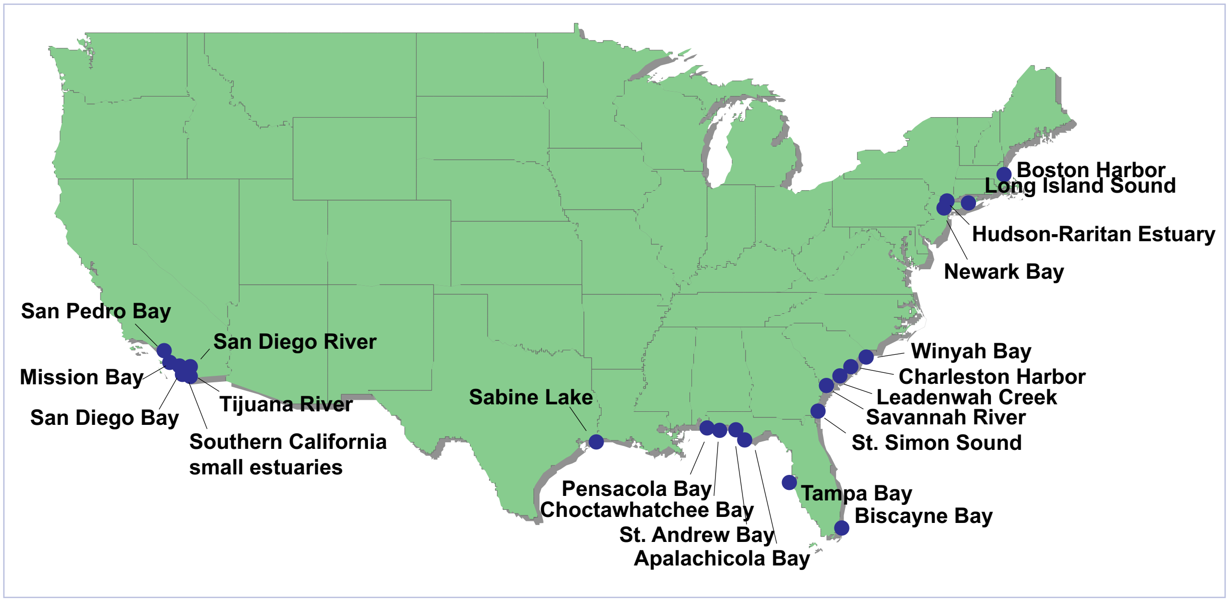


Table 1. *Spatial extent of sediment toxicity in each survey area (square kilometers and percent of study area) as estimated with each of three laboratory tests* (Long et al. 1996).

		Toxic Areas - km^2 (%)				
Survey Area	**Total survey area (km^2)**	**Whole Sediment Test**	**Sediment[a] Porewater Test**	**Organic Sediment Extract Test**	**No. of Samples**	**Date of Survey**
Boston Harbor	56.1	5.7 (10.0%)	3.8 (6.6%)	25.8 (44.9%)	55	Jun/Jul 1993
Long Island Sound Bays	71.9	36.3 (50.5%)	nd	48.8 (67.9%)	60	Aug 1991
Hudson-Raritan Esty.	350.0	133.3 (38.1%)	nd	136.1 (38.9%)	117	Mar/May 1991
Newark Bay	12.7	10.8 (85.0%)	nd	nd	57	Jan/Mar 1993
Winyah Bay	7.3	0.0	3.1 (42.2%)	5.1 (70.0%)	9	Jun 1993
Charleston Harbor	41.1	0.0	12.5 (30.4%)	17.6 (42.9%)	63	Jun/Jul 1994
Leadenwah Creek	1.7	0.0	0.0	0.3 (20.1%)	9	Jun/Jul 1994
Savannah River	13.1	0.2 (1.2%)	2.4 (18.4%)	7.5 (57.1%)	60	May 1995
St. Simon Sound	24.6	0.1 (0.4%)	0.7 (2.6%)	11.4 (46.4%)	20	Aug 1992/93
Biscayne Bay	484.2	62.3 (12.9%)	229.5 (47.4%)	248.4 (95.8%)	226	Jun 1994/95
Tampa Bay	550.0	0.5 (0.08%)	463.6 (84.3%)	0.6 (0.09%)	165	Jun 1994
Apalachicola Bay	187.6	0.0	63.6 (33.9%)	186.8 (99.6%)	9	May 1993
Choctawhatchee Bay	254.5	0.0	113.1 (44.4%)	254.5 (100%)	39	Jun 1994
St. Andrew Bay	127.0	0.0	2.3 (1.8%)	127 (100%)	31	May 1993
Pensacola Bay	245.9	0.00 (0.015%)	14.0 (5.1%)	194.2 (79.0%)	66	Aug 1995
Sabine Lake	245.9	0.0 (0%)	14.0 (5.7%)	194.2 (79.0%)	66	Aug 1995
S. Cal. Small Estuaries	5.0	2.9 (57.9%)	2.1 (42.7)	nd	30	Aug/Sep 1994
San Pedro Bay[b]	53.8	7.8 (14.4%)	52.6 (97.7%)	nd	105	Jul, Sep 1992
Mission Bay	6.1	0.0	3.6 (59.5%)	nd	11	Mar/Aug 1993
San Diego River	0.5	0.0	0.2 (48.0%)	nd	2	Mar/Aug 1993
San Diego Bay	34.0	23.5 (69.0%)	31.7 (93.2%)	nd	117	Mar/Aug 1993
Tijuana River	0.3	0.17 (24.5%)	0.27 (90.0%)	nd	6	Mar/Aug 1993
(Total toxic area/ Total area (km^2))	2532.6	(277.0/ 2532.6)	(886.3/ 2082.6)	(1482.3/ 2416.2)	1176	
Percent of total area		(10.9%)	(42.6%)	(61.3%)		

na = data not available
nd = no data (test not performed)
[a] Tests performed with 100% porewater concentrations
[b] Porewater tests performed with abalone embryos

ductive ability, or its ability to avoid infection or predators. In sufficiently high concentrations, many environmental toxicants can be fatal. Measures of such adverse biological effects are referred to as "sediment toxicity."

METHODS NOAA USES TO MEASURE SEDIMENT TOXICITY

Figure 2. *Examining sediments collected with the Young-modified van Veen grab.*

Potentially toxic substances often occur as complex mixtures in sediments, with many different chemicals occurring at different concentrations, depending upon the sources. Detailed and highly sensitive chemical analyses of the sediments can reveal the concentrations of most toxicants and identify the variety of mixtures that are present. If toxic chemicals exceed concentrations that cause biological effects, then there will be concern regarding the threat they pose to resident marine life. However, data from chemical analyses alone do not provide direct evidence of sediment toxicity. Toxicity tests are needed to detect and describe the severity and frequency of adverse biological effects associated with coastal contamination.

Site Selection and Field Methods

Numerous bays and estuaries have been identified by NOAA's National Status and Trends (NS&T) Program's Mussel Watch Project as having localized areas with elevated levels of chemical contaminants in their sediments. NOAA considered those areas in which high chemical concentrations were observed as candidates to study the extent and severity of toxicity and other adverse biological effects. Other information used in selecting bays and estuaries for sediment toxicity surveys include data from state and local monitoring programs and the availability of committed partners. To date, sediment toxicity tests have been performed in 22 coastal areas (Figure 1). The sizes of the study areas, which range from 0.3 km^2 (Tijuana River estuary, California) to 550 km^2 (Tampa Bay, Florida), the year of the survey, and the numbers of samples collected in each area are listed in Table 1.

Sampling was conducted throughout the entire expanse of each study area. Samples were not knowingly collected in the immediate vicinity of sources of contaminants, such as sewage or industrial outfalls. In surveys of Long Island Sound, Hudson-Raritan Estuary, Tampa Bay and San Pedro Bay, sampling sites were not selected randomly. In the other areas, sampling strategies have followed a stratified-random design, with random site selection within a comparable sampling area, or *stratum*, (*i.e.*, having similar salinity, depth, and sediment type in a spatially distinct area). Each study area was comprised of numerous strata. Usually, several individual samples were collected and tested within each stratum.

Sediments were collected with a seabed sampling device known as a 0.1 m^2 Young-modified van Veen grab (Figure 2). The open grab was lowered from the surface until it touched bottom, at which time the jaws snapped closed, enclosing an undisturbed volume of sediment. The closed grab was hauled back to the surface, the upper two to three centimeters of sediment were removed, then the grab was cleaned with seawater and lowered again for additional samples. Sample containers were shipped in ice chests by overnight courier to laboratories where some of the sediment was analyzed for chemical contaminants and the remainder was used in toxicity tests.

Toxicity Tests

In nearly all of the sediment toxicity surveys in this study, NOAA used a set of three toxicity tests to ensure a variety of test species, different measures of toxic responses, and multiple tests with the same sediment sample. This approach also provides comparability of test results among regions or estuaries. These three tests were the: 1) whole sediment test (ten-day amphipod survival), 2) sediment porewater test (either 1-hour sea urchin fertilization or 48-hour molluscan embryo development), and 3) organic sediment extract test (5-minute exposure of marine bioluminescent bacteria).

The tests provided independent estimates of sediment toxicity. Whole (solid phase) sediment tests employed amphipods of a uniform size that were exposed to relatively unaltered sediments. Sediment porewater tests utilized sensitive, early life stages of sea urchins and mollusks and a sediment fraction in which toxicants

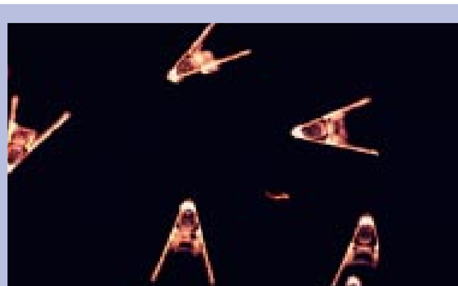
Whole Sediment Test

Amphipods are often the most common crustacean in uncontaminated sediments and have great ecological significance as prey to valuable fish and wildlife species. Small, shrimp-like animals (Figure 3), they live on or in the mud and usually scavenge among the detritus for their food. Amphipods have been widely used in sediment toxicity assessments, following standardized methods from the American Society for Testing and Materials.

In the work reported here, the tube-dwelling amphipod, *Ampelisca abdita* (Figure 3), a common resident of many Atlantic and Gulf Coast bays, was usually the test species. In the California surveys, however, the burrowing amphipod, *Rhepoxynius abronius*, often a resident of Pacific Coast estuaries, was used. Amphipods were exposed to whole sediments collected from different test sites as well as to uncontaminated sediments for comparison. After 10 days the incidence of mortality in test sediment samples relative to uncontaminated controls was noted as the measure of toxicity.

Figure 3. *Photo showing test organism* ***Ampelisca abdita*** *(1-3 mm. in length).*

Figure 4. *Photo showing microscopic **Arbacia punctulata** larvae.*



Sediment Porewater Test

Sea urchins are common inhabitants of the seabed in uncontaminated areas. During reproduction, they shed large quantities of eggs and sperm into the sea. Fertilized eggs develop into free-floating larvae that remain as plankton for several weeks or more before settling to the bottom, often colonizing areas distant from their origin. The fertilization process is sensitive to many environmental factors, including the presence of contaminants in the water.

Toxicity tests in most cases were performed with eggs from the sea urchin *Arbacia punctulata* (Figure 4). Toxicity tests of San Diego Bay samples, however, were performed with the Pacific coast purple sea urchin, *Strongylocentrotus purpuratus*; while tests of San Pedro Bay samples used the embryos of the red abalone, *Haliotis rufescens*.

Sediment porewater (the subsurface water contained in spaces among the individual grains of sediment) was squeezed or centrifuged from the sediment samples. After the introduction of sperm, eggs of the urchins or mollusks were then placed in various dilutions of porewater. This report includes results on exposures to undiluted or 100% pore water only. Either the rate of successful egg fertilization and/or the percentage of normally shaped embryos of either the urchins or mollusks are reported relative to experimental controls.

are believed to be highly bioavailable. Finally, the organic sediment extract tests examined toxicity to bioluminescent bacteria. This toxicity is attributable to contaminants extractable with organic solvents. These tests are intended to provide measures of adverse response to contaminant exposure. Taken together, the tests covered a variety of organisms and different components of the contaminated sediment. Additionally, all three tests have been widely used by other agencies and private industry so the results can be compared to those of others.

Statistics and Assumptions used to Determine Extent of Toxicity

All the toxicity tests included replicate measurements. Data were analyzed statistically to determine the minimum biological response that could be considered a significant effect of sediment contaminants. For example, in amphipod toxicity tests, any survival value less than 80% of the control value was considered a toxic sample. Results of the toxicity tests were weighted to the areal extent of each sampling site within each stratum to estimate the spatial extent of toxicity.

SEDIMENT TOXICITY RESULTS

Where NOAA has Found Toxic Sediments

NOAA has found one or more samples that were toxic in at least one test in all of the areas surveyed thus far (see Figure 1). Each area also had samples that

Organic Sediment Extract Test

Certain marine bacteria are capable of bioluminescence. Attenuation of light output by these organisms has been related to contaminant-induced disruption of cellular metabolism. One specific bacterium, *Photobacterium phosphoreum*, has been used in a standardized test known as Microtox™ (Figure 5). The Microtox™ test was employed in most (17 of 22) of the surveys conducted during these studies.

Potentially toxic chemicals in the sediments were extracted with an organic solvent. Sediment samples were exposed to an organic solvent (dichloromethane), and the resulting extract was added to test tubes at various dilutions. Cultures of the bioluminescent bacteria were dispensed into test tubes. In this test, a decrease in bioluminescence relative to controls indicates an impairment of normal cellular activity. The extract concentration that produces a 50% or greater reduction in bioluminescence relative to controls is the measure of toxicity.

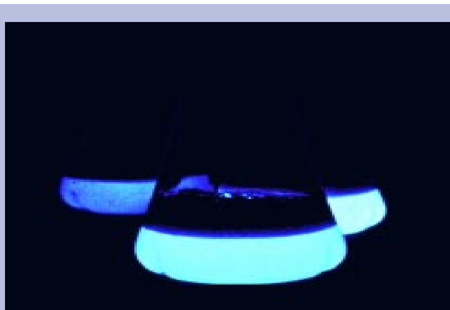


Figure 5. *Flasks containing bioluminescent bacteria, **Photobacterium phosphoreum**, in a darkened room.*

were not toxic in all the tests. The severity, prevalence, and spatial extent of toxicity varied considerably among the different survey areas. Each area surveyed showed different characteristics in sediment toxicity.

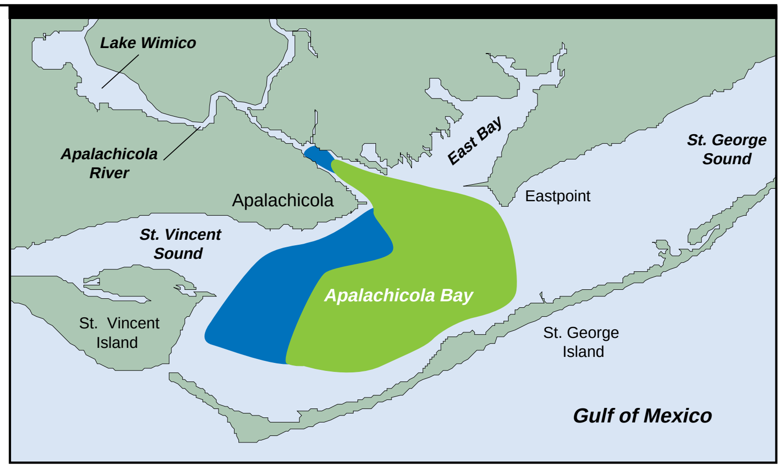
Spatial patterns in toxicity for each of the major survey areas are displayed in Figure 6. For each of these figures, the areas depicted in blue were not toxic in any of the three tests performed. Areas shown in green were toxic only in the most sensitive sediment tests (*i.e.,* urchin fertilization, molluscan embryo development or microbial bioluminescence but not in amphipod survival). Areas shown in yellow were toxic in at least the whole sediment tests performed with the amphipods. To emphasize the limited areal extent of severe toxicity, areas shown in red are those where amphipod survival was less than 40% of that in controls.

Comparison of Spatial Toxicity Among Bays

Sediment toxicity surveys yield important information on the potential ecological impacts of sediment contaminants. The 22 surveys that have been conducted to date are a substantial start on a national picture of sediment toxicity in U.S. coastal waters (Figure 7 and Table 1). Taken as a whole, they provide coastal resource managers, as well as the public, with an initial assessment of environmental contamination as reflected in the benthic environment.

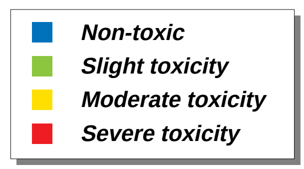
Apalachicola Bay, FL

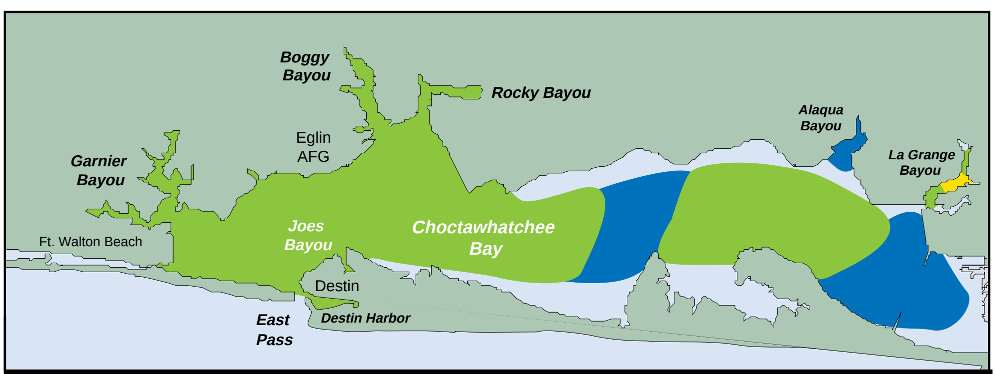
None of the samples were severely or moderately toxic. Samples from locations scattered throughout this bay were slightly toxic in the sea urchin and Microtox tests. Notably, several samples from the eastern lobe of the bay and the lower Apalachicola River showed slight toxicity.



St. Andrew Bay, FL

In this bay none of the samples were severely or moderately toxic. Samples that were slightly toxic in only the Microtox tests were scattered throughout the entire system. Samples from several small adjoining bayous (notably Massalina and Watsons bayous) near Panama City showed the highest toxicity in the Microtox tests.

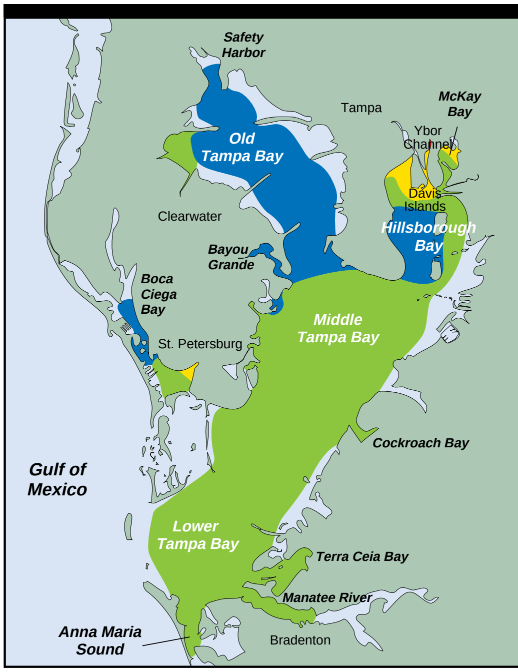




Choctawhatchee Bay, FL

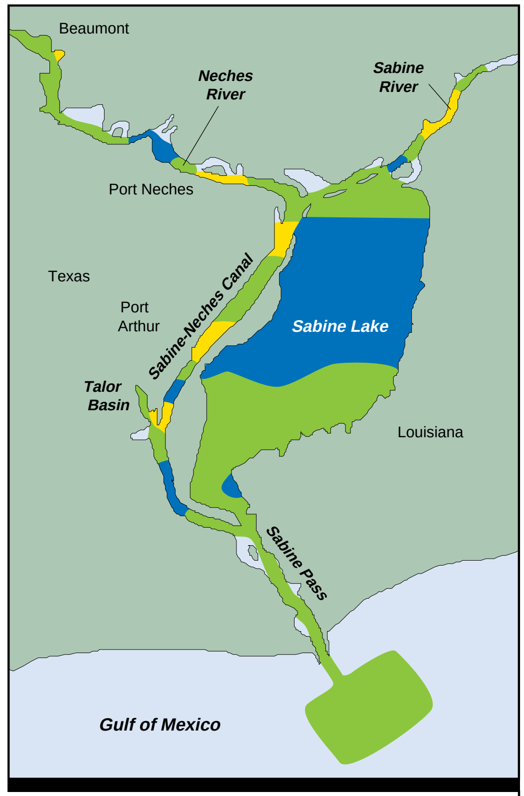
None of the samples were severely toxic. Moderately toxic samples were collected in La Grange Bayou. Samples collected throughout much of the system were slightly toxic, with toxicity in only the Microtox tests. Samples from Garnier Bayou near Fort Walton Beach showed highest toxicity in the Microtox tests.

Figure 6. *Regional maps depicting the spatial extent of sediment toxicity in coastal embayments along the Atlantic, Gulf of Mexico, and Pacific shores of the United States. Lack of shading indicates that the area was not sampled by NOAA.*



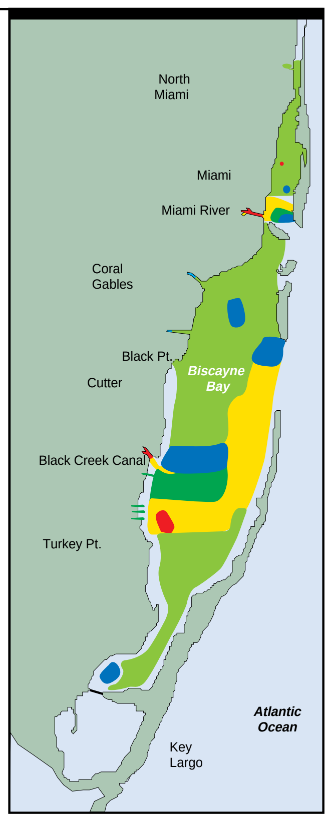
Tampa Bay, FL

Severe toxicity in this very large system was restricted to relatively small regions of northern Hillsborough Bay, specifically upper Ybor Channel. Moderately toxic samples were found in portions of McKay Bay, northern Hillsborough Bay around the Davis Islands, and south of St. Petersburg in Boca Ciega Bay. Much of southern Hillsborough Bay, middle and lower Tampa Bay were slightly toxic. Sandy sediments in much of Old Tampa Bay were non-toxic.



Biscayne Bay, FL

Severe toxicity occurred only in the Miami River, in Black Creek canal, and in an area east of Turkey Point in the southern reaches of the bay. Moderately toxic conditions were apparent in a large portion of the southern bay and in a portion of the central bay east of Miami. Elsewhere, most of Biscayne Bay was slightly toxic.



Sabine Lake, TX

None of the samples showed severe toxicity. Moderately toxic sediments were scattered along several reaches of the intercoastal waterway. Most of the length of the waterways and the northern and southern ends of Sabine Lake were slightly toxic. Slightly toxic conditions extended offshore into the Gulf of Mexico. Much of central Sabine Lake was non-toxic.

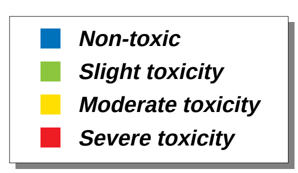
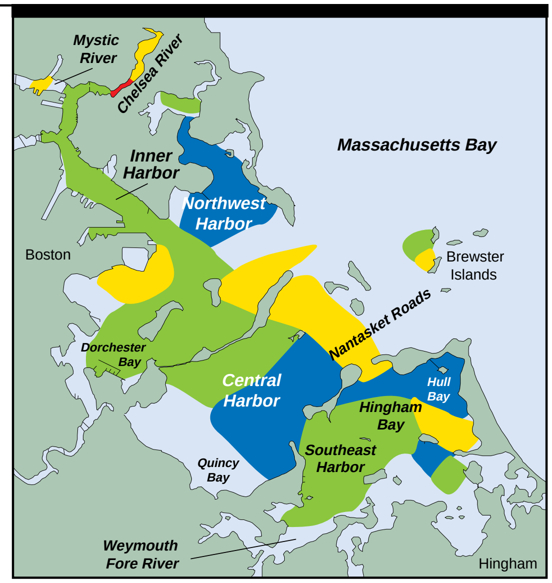
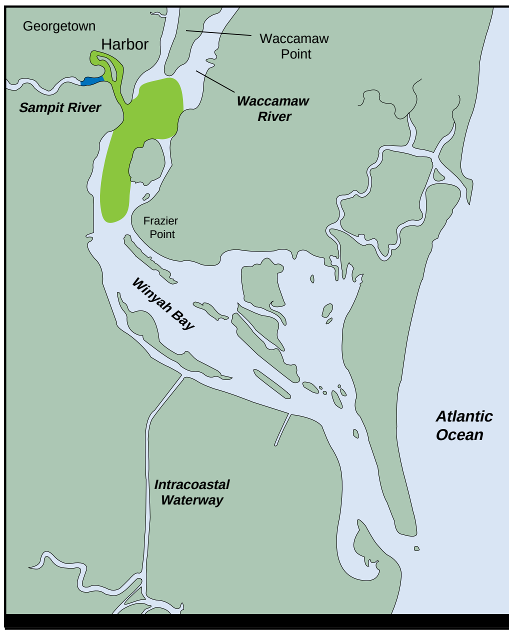


Figure 6 continued.

Boston Harbor, MA

Samples scattered throughout the harbor and even beyond the harbor entrance showed toxicity in some of the tests; however, toxicity was most severe in portions of the upper Chelsea River and moderately toxic in portions of the northwest and central harbor areas. Slightly toxic conditions were observed throughout most of the inner harbor. Samples from some portions of northwest, central and southeast harbor were



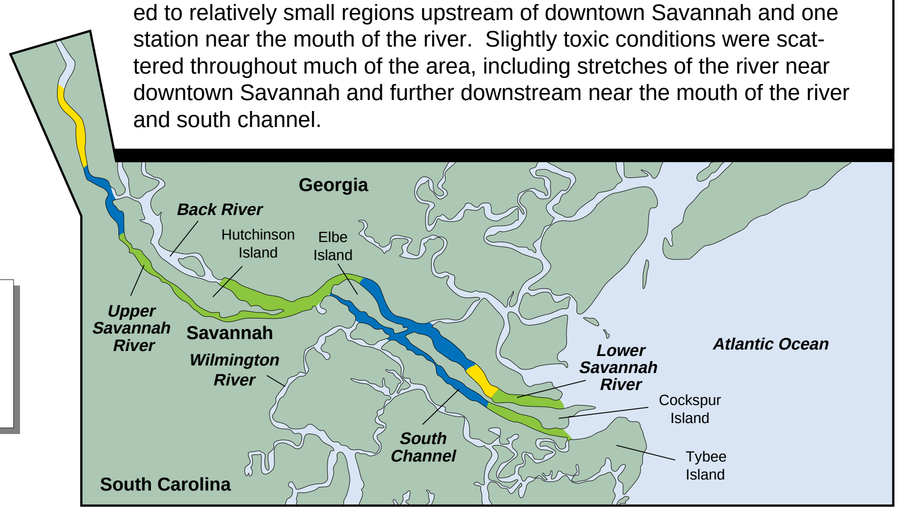


Winyah Bay, SC

Samples from the Georgetown Harbor in the upper reaches of the survey area were slightly toxic. Slightly toxic conditions extended down the bay throughout all sampling stations. None of the samples were severely or moderately toxic.

Savannah River, SC/GA

None of the samples were severely toxic. Moderate toxicity was restricted to relatively small regions upstream of downtown Savannah and one station near the mouth of the river. Slightly toxic conditions were scattered throughout much of the area, including stretches of the river near downtown Savannah and further downstream near the mouth of the river and south channel.



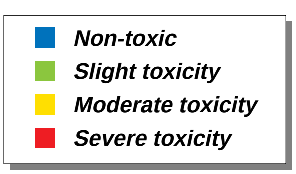
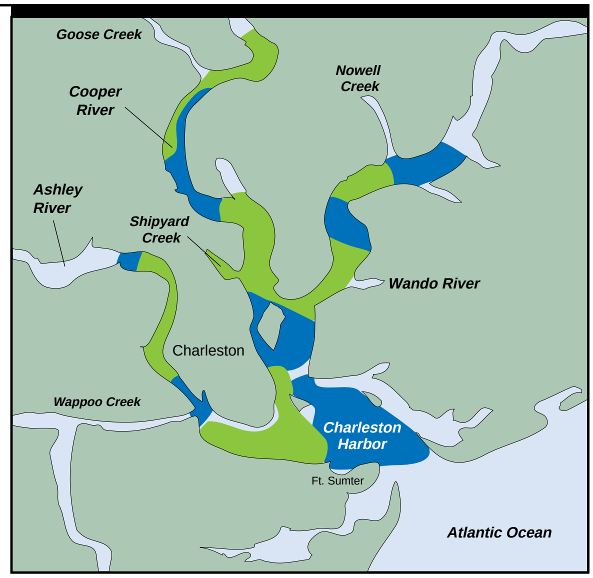
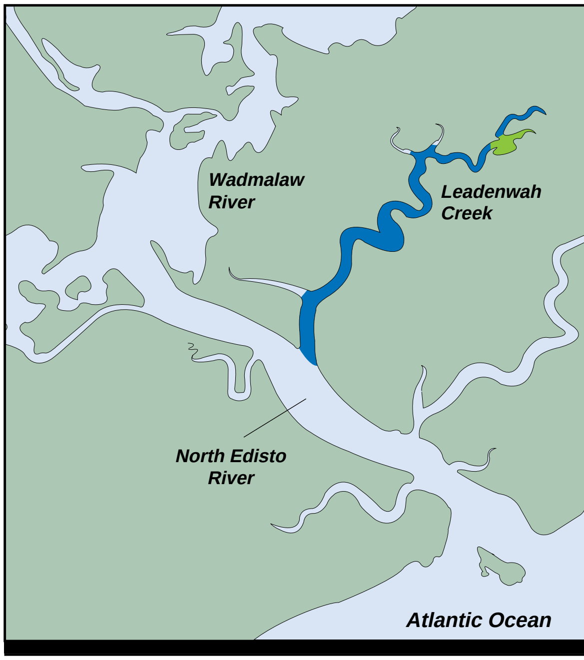


Figure 6 continued.

Charleston Harbor, SC

None of the samples were severely or moderately toxic. Slight toxicity was observed in stations scattered along the Cooper and Ashley rivers, in Shipyard Creek, and near Charleston. Slightly toxic or non-toxic condtions were found in most of the lower Wando River and lower harbor.



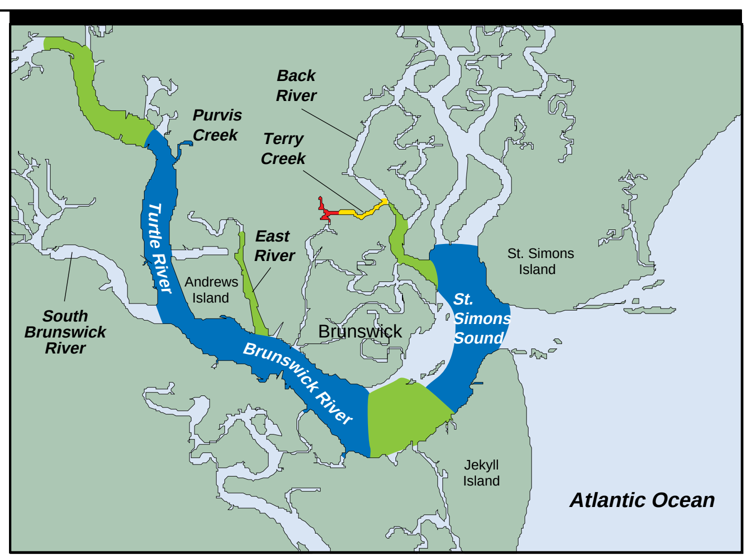


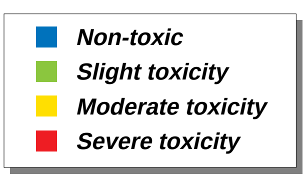
Leadenwah Creek, SC

No severe or moderate toxicity was found in this tidal creek which frequently receives pesticide runoff from nearby agricultural fields. However, one of the samples from the upper reaches of the creek showed slight toxicity.

St. Simons Sound, GA

Samples from one small and relatively isolated region of the bay (Terry Creek) were severely or moderately toxic. Some samples from the East River and lower Brunswick River near the port of Brunswick, upper Turtle River, and lower Back River were slightly toxic. However, toxicity diminished quickly toward the mouth of the estuary.





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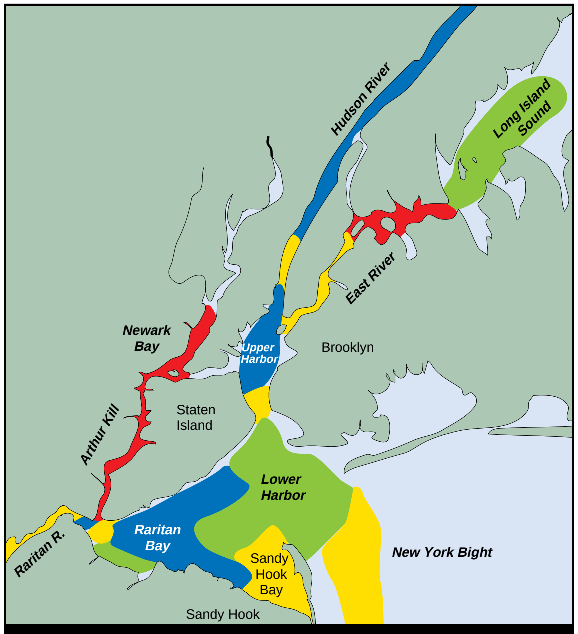
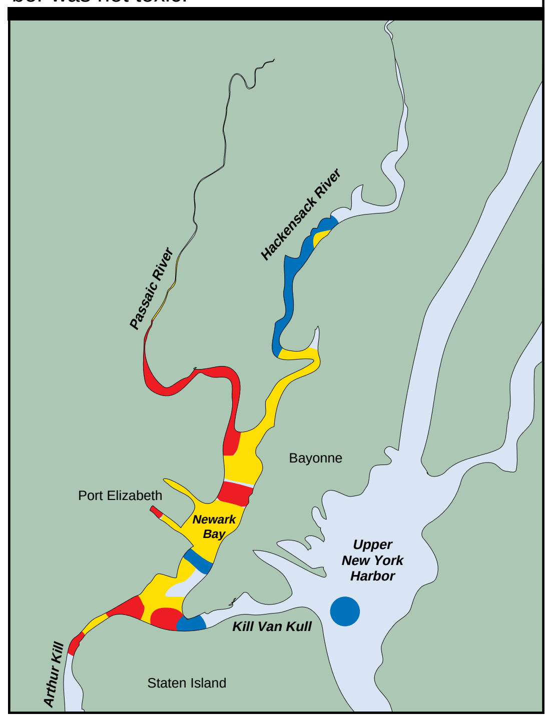


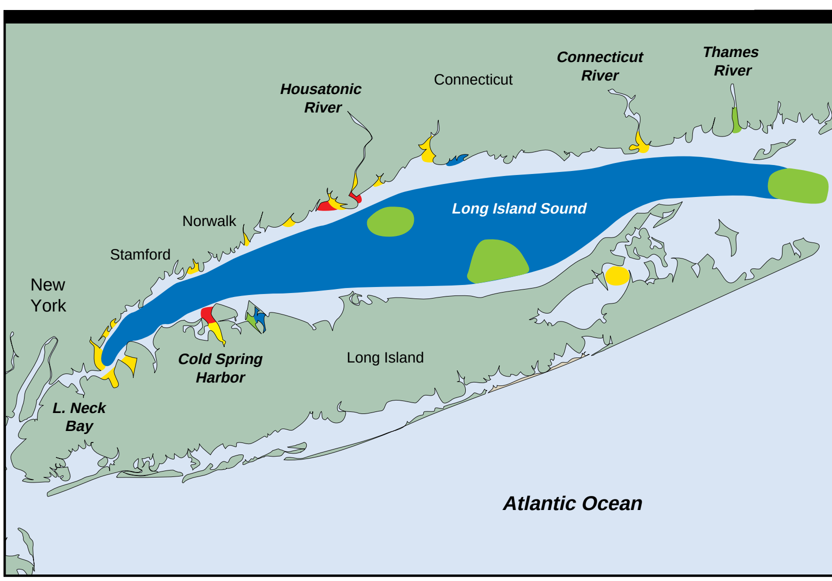
Hudson-Raritan Estuary, NY/NJ

Among all areas studied thus far, toxicity in the amphipod tests was most pervasive in this area when sampled during 1991. Several regions were notably most toxic, including the upper and lower reaches of the East River, the Newark Bay/Arthur Kill region, and inner Sandy Hook Bay. Moderate toxicity also was observed in portions of the lower Raritan River, Raritan Bay, and the upper New York harbor. However, much of the upper New York Harbor, lower harbor, lower Hudson River and southern Raritan Bay were among the least toxic areas. Some moderate toxicity was observed beyond the harbor entrance in the New York Bight.

Newark Bay, NJ

Following the 1991 Hudson-Raritan survey, a more intensive survey of Newark Bay was conducted in 1992. Toxicity was severe in the lower Passaic River, Arthur Kill, and throughout all of Newark Bay. Samples from the lower Hackensack River were either non-toxic or moderately toxic and a sample from the upper New York harbor was not toxic.





Long Island Sound Bays NY/CT

Severe to moderate toxicity occurred in most of the 20 bays that were sampled along the Connecticut and Long Island shores. Toxicity was most severe among many of the westernmost bays nearest the confluence with the upper East River. Toxicity was either slight or not found in samples collected in the main basin of the Sound.

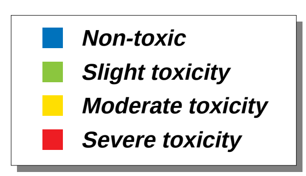
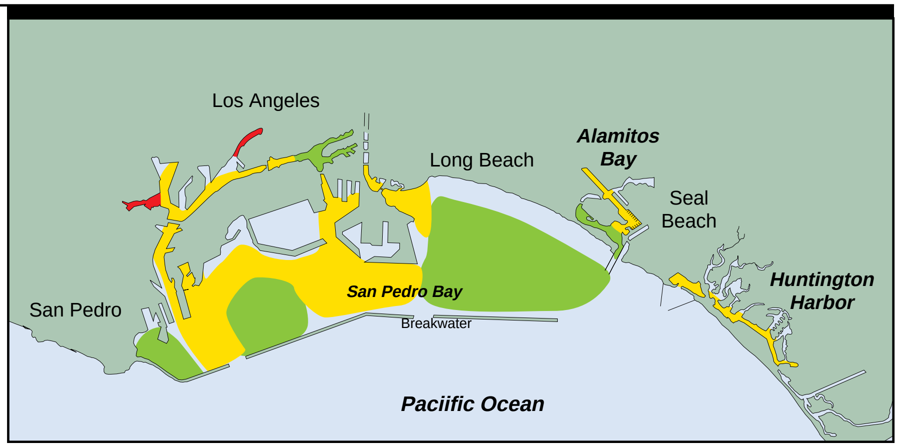
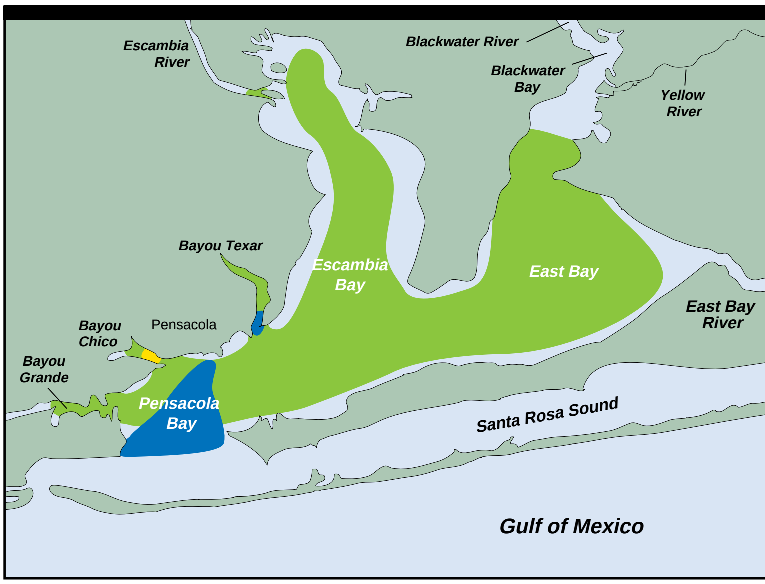


Figure 6 continued.

San Pedro Bay, CA

Severe toxicity was found in two channels of the inner Los Angeles/Long Beach Harbor. Much of the inner Los Angeles/ Long Beach harbor, inner San Pedro Bay, Alamitos Bay, and Huntington Harbor was moderately toxic. Slightly toxic samples were collected in regions of outer San Pedro and Alamitos Bays. Toxicity generally diminished seaward toward the San Pedro Bay breakwater.



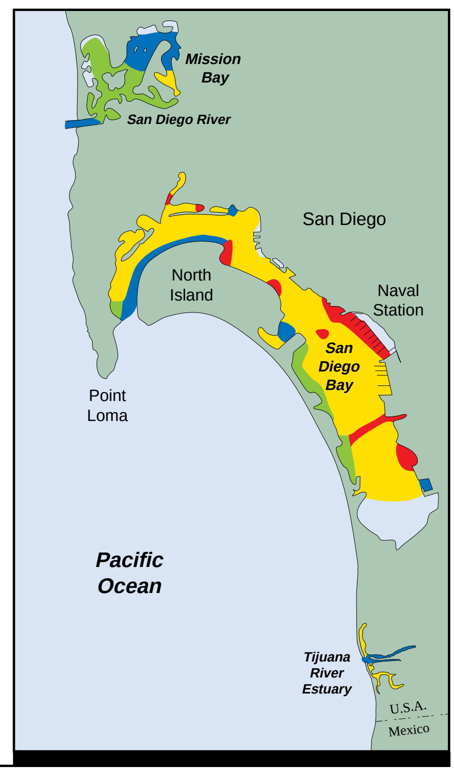


Pensacola Bay, FL

None of the samples showed severe toxicity. Moderate toxicity was restricted to a portion of one adjoining bayou (Bayou Chico). Slight toxicity observed only in the Microtox tests was pervasive throughout most of the system.

San Diego Bay, CA

Samples that showed severe toxicity were collected at many locations scattered throughout the bay. Some regions of the bay near the Naval Station, near San Diego, within boat basins and marinas, and within adjoining creeks and stormwater channels were severely toxic. Moderate toxicity was observed throughout most of the regions of the Bay. Toxicity generally diminished toward the entrance and was not apparent in samples collected near the ocean. Portions of Tijuana River estuary and Mission Bay were moderately toxic.



Non-toxic
Slight toxicity
Moderate toxicity
Severe toxicity

Figure 6 continued.

Tests of amphipod survival were performed in all surveys. In these tests, toxicity was most widespread in Newark Bay (85% of the area), San Diego Bay (69%), Long Island Sound bays (50%), and the Hudson-Raritan Estuary (38%; Table 1). Toxicity in the amphipod survival tests was least prevalent in the bays of the southeast (South Carolina, Georgia, and Florida). Only a few samples from Tampa Bay, one of the largest systems studied thus far, were toxic in these tests. Approximately 10% and 14% of Boston Harbor and San Pedro Bay tested toxic, respectively. In Biscayne Bay, toxicity was apparent in the lower Miami River and in several strata in the southern reaches of the system, representing approximately 13% of the area.

Toxicity to invertebrates exposed to 100% porewater was most prevalent in San Pedro Bay (98%), San Diego Bay (93%), Tampa Bay (84%), and the Tijuana River estuary (90%; Figure 8, Table 1). Approximately 30-45% of Apalachicola Bay, Charleston Harbor, Choctawhatchee Bay, and Winyah Bay showed toxicity in these tests. Less than 20% of Boston Harbor, Pensacola Bay, Savannah River, St. Andrew Bay, and St. Simons Sound was toxic in these tests. In Tampa Bay and San Pedro Bay, the results of the sea urchin and abalone embryo tests, respectively, contrasted remarkably with those of the amphipod tests. With some notable exceptions (*e.g.*, Boston Harbor), the spatial extent of toxicity was much higher in the

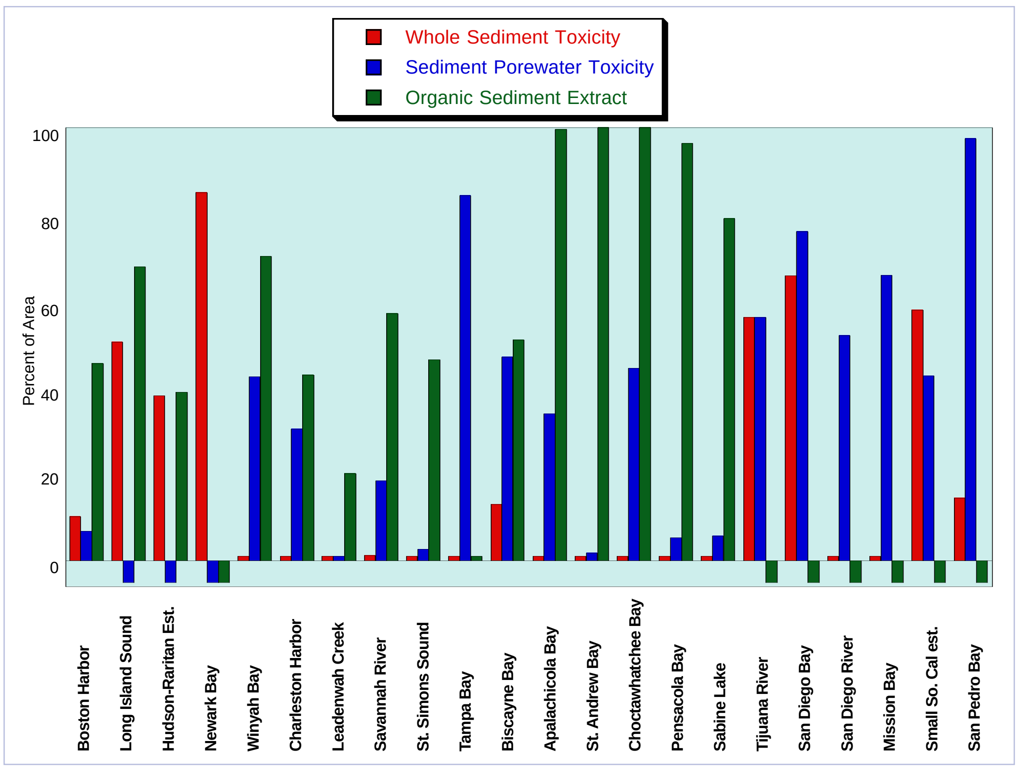


Figure 7. *Percentages of each survey area in which toxicity was observed in three tests: amphipod survival, urchin fertilization (urchin embryo development or abalone development in California), or microbial bioluminescence. Negative values indicate no test was done.*

porewater tests than in the amphipod tests.

Toxicity as inferred from the microbial bioluminescence test was most pervasive (99-100%) in the four segments of the western Florida panhandle: Apalachicola, Choctawhatchee, Pensacola, and St. Andrew Bays (Table 1). Also, approximately 80% and 70% of Sabine Lake, TX, and Winyah Bay, SC, respectively, were toxic. Approximately 40-60% of Boston Harbor, Charleston Harbor, Hudson-Raritan Estuary, Savannah River, Biscayne Bay, and St. Simons Sound tested toxic. In Tampa Bay, the spatial extent of toxicity in the microbial tests was minimal, approximating that of the amphipod survival tests (less than 1%). These tests were not performed in the California Bays.

Several spatial patterns in the results became obvious in these studies. First, severe toxicity (<40% amphipod survival) was most prevalent in the northeastern U.S. bays (notably Newark Bay and inner waterways; and urbanized harbors adjoining Long Island Sound and the Hudson-Raritan Estuary) and in several bays of South California (notably San Diego Bay and San Pedro Bay). Severe toxicity was least prevalent in many of the large estuaries of the southeastern United States: Florida, Georgia and South Carolina. Second, severe toxicity was largely restricted to highly industrialized and urbanized bayous, basins, rivers, inner harbors, and marinas (Figures 9 and 10) and generally diminished down-estuary toward the ocean. An exception was Newark Bay in which toxicity was pervasive throughout the entire system. Third, the spatial patterns of toxicity indicated with different toxicity tests often overlapped.

Large-Scale Estimates of Toxicity

Combining the data from all areas, toxicity was observed in the amphipod survival test (the least sensitive test) in approximately 11% of the surveyed area nationwide (Figure 8). This estimate

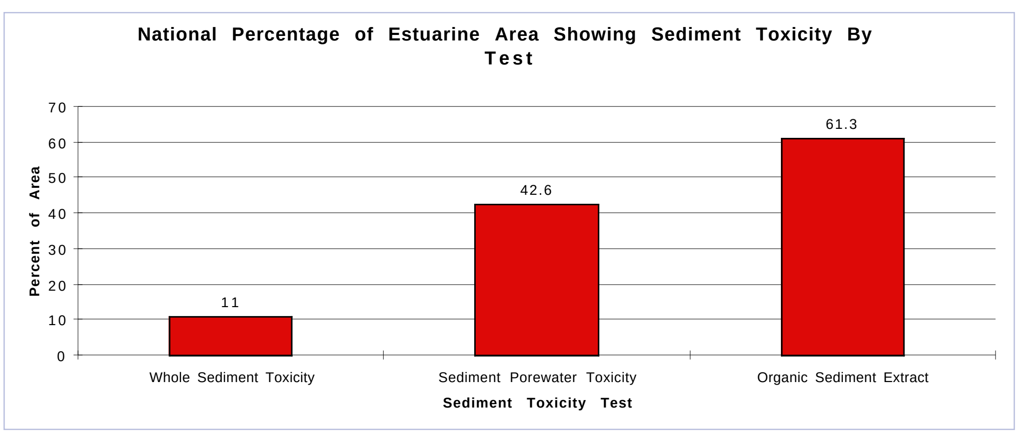


Figure 8. *National percentage of coastal areas with toxic responses by laboratory organisms to three different sediment exposure tests.*

Figure 9. *Seaside condominiums, hotels, and urban centers alter natural habitats and tend to have areas with severely toxic sediments.*

may change as more areas are surveyed in the future; however, large changes are not expected. Although the sea urchin, mollusk, and Microtox™ tests were not conducted in every study, they generally indicated a wider occurrence of toxicity. The spatial extent among all areas combined was 42.6% in the sea urchin/mollusk bioassays of porewaters and 61.3% in the Microtox™ tests of solvent extracts. The discrepancy among the three tests is to be expected since it emphasizes the markedly different nature and probable mechanisms of toxic effects of contaminants. It is also instructive in itself, because it serves as a caution against relying on only one type of test organism or sediment component.

The U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program-Estuaries (EMAP-E) studied the spatial extent of sediment toxicity as an indication of degraded benthic infaunal communities. Using comparable methods and the same species of amphipod (*i.e.*, *Ampelisca abdita*) as in the NOAA studies, EMAP identified approximately 10% of the sampled area of the Virginian Province (Cape Cod, Massachusetts, to Cape Henry, Virginia) as containing toxic sediments. An estimated 20% of the Carolinian Province (Cape Henry, Virginia, through the southern end of the Indian River Lagoon, Florida) had degraded benthic infaunal assemblages accompanied by high sediment contamination and/or significant sediment toxicity based on a Microtox™ assay. Whereas approximately 10% of the sediments in the Louisianian Province (*i.e.*, from Anclote Key, Florida to the Texas/Mexico border) were toxic to mysid shrimp, only 1% of sediments were toxic to the amphipod *Ampelisca*.

Figure 10. *Industries, marinas, and private residences along restricted coastal waterways may be sources of toxic sediments.*

DISCUSSION OF WHAT HAS BEEN LEARNED

Implications of Sediment Toxicity for Coastal Ecosystems

The primary purpose of these toxicity tests was to compare potential sediment toxicity of different areas using consistent methods with quality assurance procedures. By using similar methods and standardized tests, toxicity data can be used to compare conditions throughout a bay, as well as among different bays, throughout a region, and to describe changes in conditions over time.

A wide variety of toxicity tests can be performed to infer the types of adverse effects that can occur in the environment. NOAA used three standard toxicity tests in most study areas for comparability of data. These tests employed a variety of species (bacterium and invertebrates) and different life stages (gametes, embryos, juveniles), different measures of toxicity (mortality, physiological stress, impaired reproduction and/or larval development), and different exposure media (whole sediment, porewater, and extracted contaminants). As with all bioassays, each of the toxicity tests used by NOAA has its own inherent limitations.

Total combined estimates of the spatial extent of toxicity probably would differ if other tests with different sensitivities had been used. The overall estimates of the spatial extent of sediment toxicity in coastal waters would almost assuredly be different if data were generated from the open waters of the continental shelves.

Application of Sediment Toxicity Information by State/Federal Managers

Data on sediment toxicity have played important roles in the nation's efforts to improve and manage the coastal environment. In its partnerships with local and state governments and with other federal agencies, NOAA has participated in the identification of areas needing particular attention in sediment toxicity assessment surveys. Partnerships with the California State Water Resources Control Board in Sacramento, the Florida Department of Environmental Protection in Tallahassee, the Tampa Bay National Estuary Program in St. Petersburg, the Massachusetts Bay National Estuary Program in Boston, the State of South Carolina's Charleston Harbor Program in Charleston, the Dade County Department of Environmental Resources Management in Miami, and the U.S. EPA Region 2 in New York City have led to improved field operations and timely dissemination of study results for use in coastal management decisions.

Data from Tampa Bay were instrumental in the identification and quantification of sediment toxicity problems that were addressed in the Tampa Bay Comprehensive Conservation and Management Plan prepared by the National Estuary Program office. The data from all the surveys in California were used to satisfy a legislative mandate to improve sediment quality throughout the state. Data from Newark Bay, Charleston Harbor, and St. Simons Sound were used to further estimate the spatial scales of toxicity in the vicinity of high priority waste sites that were under investigation. In Biscayne Bay, data from the NOAA surveys played an important role in decisions regarding the improvement of sediment quality and dredging in the Miami River and several canals adjoining the southern reaches of the bay. Information from most areas has also been used by NOAA's Hazardous Materials Response and Assessment Division in its risk assessments of high-priority waste sites.

On a national scale NOAA's estimates of the spatial scales of sediment toxicity were incorporated into concurrent estimates of the extent of chemical contamination of sediment prepared by the U.S. EPA as a part of the National Sediment Quality Survey. NOAA data provided important estimates of the spatial extent of toxicity compiled throughout numerous estuaries concurrently with similar estimates for other areas prepared by the U.S. EPA'S Environmental Monitoring and Assessment Program.

Data on sediment toxicity and sediment contamination have been used to develop numerical guidelines to evaluate probable biological effects associated with contaminants. These guidelines, known as Effects Range-Low (ERL) and Effects Range-Median (ERM) delineate contaminant concentration ranges that are rarely, occasionally, or frequently associated with adverse biological effects. These guidelines have been widely used in assessing sediment quality in coastal waters in the United States and elsewhere.

Methods for designing sediment toxicity surveys, performing analytical tests, and evaluating data compiled during the NOAA surveys have been shared with other agencies and programs. These basic methods have been adopted in sediment assessments performed in Boston Harbor by the state of Massachusetts, in Charleston Harbor by the state of South Carolina, in freshwater canals of South Florida by Dade County, in the St. John's River by the state of Florida, and in Pearl Harbor, Hawaii by the U.S. Navy.

FUTURE WORK

Assessing the extent and severity of contamination of coastal waters from toxic chemicals and determining the nature of biological effects of such contamination are important elements of NOAA's strategic goal of sustaining the overall health and economic productivity of the nation's coastal environments. However, it should be emphasized that toxic chemicals are not the only serious anthropogenic threat to the coastal and estuarine areas. Nutrient over-enrichment, over-harvesting of fish and shellfish, habitat loss, and other factors play major roles in contributing to coastal environmental degradation and concomitant economic losses.

NOAA's National Status and Trends Program has conducted a series of field surveys to provide initial estimates of the extent and magnitude of environmental degradation in our coastal areas as a result of exposure to anthropogenic toxic chemicals. Our present national assessment is based on survey results from 22 coastal bays and estuaries around the United States. A number of large bays (such as Puget Sound, San Francisco Bay, and Delaware Bay) and several smaller bays (such as Grays Harbor in Washington, and Mobile Bay in Alabama) have not yet been surveyed with field sampling and toxicity testing comparable to those used in this study. Planning for sediment toxicity assessment in these and other coastal areas during the next five years is underway. Field surveys in Puget Sound and Delaware Bay began in summer 1997.

The sediment toxicity information in this report is from studies completed during the period 1991-96. Recently, these studies were expanded to develop a more comprehensive approach to assessing degraded sediment quality and ecological implications. The concept of a *Sediment Quality Triad* is being used to diagnose relationships among measures of sediment contamination, sediment toxicity, and macrobenthic community response to degraded environment. The macrobenthos, animals larger than 0.5 mm that live on or in the bottom sediment, are sampled at the same sites where sediment toxicity and contaminant measurements are made. Macrobenthic species comprise the foundation of food webs that sustain highly valued fish and wildlife populations. The impact of contamination on coastal ecosystems should be evident by patterns in data on chemistry, toxicity and macrobenthic community structure in a given region.

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